Nanocrystal Shape Control Boosts Efficiency of New Solar Cells

A research team led by Paul Alivisatos has fabricated novel semiconductor nanocrystal-polymer solar cells. By controlling the shape of the nanocrystal, surprisingly high efficiencies are attained. An account of the research appeared in *Science* (March 29, 2002).

The LBNL team fabricated its new solar cell from a colloidal solution of CdSe semiconductor nanocrystals in the semiconducting polymer, poly-(3 hexylthiophene) (P3HT). Spin casting the solution on top of a transparent electrode gives a uniform, high quality, flexible thin film with a high surface area of donor-acceptor junctions suitable for charge generation and collection. A conducting top layer and suitable contacts (see figure) are then added.

These cells produce an electric current when a photon generates an “electron-hole pair” at a “donor-acceptor interface” between the hole-transporting donor polymer and the electron-transporting acceptor nanocrystals. Charge transfer occurs at the donor-acceptor interface and the electric field resulting from the work function difference of the electrodes causes the electron and hole to move in opposite directions, generating the electric current. This photon-to-current conversion occurs at the nanometer scale; thus the development of methods for controlling materials on this scale (see, for example, MSD Highlight 99-4) creates new opportunities for future generations of more advanced solar cells.

These advances are required because, although solar cells based on inorganic semiconductors such as silicon and gallium arsenide have achieved high efficiencies and have found a variety of markets, more widespread applications remain limited by the cost of production, which often involves high temperature (400-1400 ºC) and high vacuum processing and many lithographic steps.

The team explored the effect of the shape of the nanocrystals on cell performance. Cells made with 7 nm diameter spherical nanocrystals had an external quantum efficiency (the fraction of photons at a given wavelength that are converted to electron-hole pairs and then transported out of the device) of about 20% when illuminated with visible light. Use of rod-like nanocrystals partially aligned in the direction of current flow increased this value to over 50%. (In a conventional high-performance solar cell illuminated with visible light this value can approach 100%.) In further tests, the ability of the cell to generate electrical power was evaluated by measuring the power conversion efficiency, the ratio of the power generated by the cell to the power of the light incident on the cell. (With an average solar energy flux of 1000 W/m^2, a cell with an area of 1 square meter with a 10% solar power conversion efficiency would generate 100 W of power). The power conversion efficiency of a cell with elongated nanocrystals (7 nm x 60 nm) was 6.9% with green light (515 nm), one of the highest values ever reported for a polymer-based solar cell. Using the broad spectrum of simulated sunlight, the power conversion was 1.7%. While below the 10% values achieved for amorphous Si solar cells or the nearly 30% achieved for the most advanced single crystal devices, this value compares very well to those achieved by the best polymer devices (ca. 2.5%). Absorption of a larger fraction of the solar spectrum should increase the power conversion efficiency. Thus, increasing the diameter of the nanorods, which would allow cells to absorb light down to 700 nm while retaining good conversion at shorter wavelengths, or use of nanocrystals made of other materials, such as CdTe, InP or $CuInS_2$ which absorb in the red and infrared, should further increase efficiency.

This work demonstrates that the unique features of nanosized objects, combined with our ability to manipulate their shape, can be utilized to fabricate solar cells with properties not observed in organic or conventional inorganic solar cells. Furthermore, the methods used to achieve good charge transport in these nanorod solar cells can be extended to other optoelectronic applications, such as photodetectors and light emitting diodes.

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